THE EFFECTS OF RESTRICTED FIELD-OF-VIEW ON SPATIAL LEARNING WHILE NAVIGATING: IMPLICATIONS FOR STRATEGY USE AND COGNITIVE LOAD

by

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ABSTRACT

Research suggests that spatial memory while navigating with severely degraded acuity demands the use of limited cognitive resources. Peripheral vision is also a vital aspect of successful navigation, both for sensory cues and for obstacle avoidance. In a series of studies, we examined how restricted peripheral field during navigation influences spatial memory (Experiments 1-3). Participants walked on novel real-world paths wearing goggles that restricted the field-of-view (FOV) to severe (4˚, 10˚, or 15˚) or mild angles (60˚) and then pointed to remembered target locations using a verbal reporting measure. Only the most severe restriction (4˚) showed impairment in pointing error compared to the mild restriction (within-subjects). The 4˚ condition also showed an impairment in reaction time to a secondary attention task, suggesting that navigating with 4˚ FOV demands the use of limited cognitive resources. This comparison of different levels of field restriction suggests that peripheral field loss does not negatively affect spatial memory for navigation until the restriction is very severe (4˚). Additionally, we examined the effectiveness of slower walking speed as a strategy to offload the cognitive costs of navigating with severely restricted FOV (Experiment 4). Results suggest that walking speed may negatively affect cognitive resources in general, but not spatial memory for object locations.

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CHAPTER 1

INTRODUCTION

The prevalence of clinical low vision is high in the United States but receives relatively little attention—the National Eye Institute estimated in 2010 that over 4 million Americans had low vision (nei.nih.gov/eyedata). The majority of low vision cases included age-related macular degeneration, cataracts, and glaucoma (Eye Diseases Prevalence Research Group, 2004). Since many of these individuals still retain at least some of their vision, it is important to consider how they perceive their environments and how this translates functionally into spatial cognitive abilities. In many low-vision cases, individuals experience deficits in both acuity/contrast and visual field. In others, individuals experience an extreme deficit in just one part of their vision (either degraded acuity and contrast or some type of peripheral or central field loss).

A fair amount of research has examined how individuals with visual impairment are able to move through the environment. An entire medical specialty has been developed to assist blind individuals with daily movement through the world. Orientation and Mobility (O&M) specialists teach blind individuals how to effectively search their environments and interact with objects in space (see Guth & Rieser, 1997), but this field works mostly with individuals with total blindness, rather than those with a range of vision loss such as in low vision. Research suggests that people with low vision, particularly field-loss, may have more of a need for the assistance of O&M specialists than even those with total blindness (see Rieser et al., 1992). There is conflicting evidence regarding the severity of different types of visual impairment on related spatial abilities. While some studies indicate that early onset visual impairment (field loss specifically) may have a stronger negative impact on spatial abilities (Rieser et al., 1992), others suggest that people with early onset visual impairments are not as strongly affected as those with late onset because they have developed compensatory mechanisms (Monegato, Cattaneo, Pece, & Vecchi, 2007). Others still suggest that it is not the age of onset of visual impairment that makes a difference, but individual differences that are reflected in strategy use (Hill & Rieser, 1993).

The O&M specialty is focused on training blind and visually impaired individuals to physically move and orient themselves in their environment, which may subsequently aid in their memory for the space. What is discussed, but not fully answered, in the literature is why we observe these spatial learning and memory impairments with vision loss. Rand, Creem-Regehr, and Thompson (2015) pose a potential explanation for the negative effect of simulated degraded contrast and acuity on spatial memory for navigation. They suggest that the act of navigating with severely degraded acuity and contrast demands the use of limited cognitive resources that may otherwise be devoted to attending to spatial locations (and thus negatively affecting spatial memory). Research also shows that field loss, both simulated and clinical, negatively impacts spatial memory (*simulated*-Fortenbaugh, Hicks, Hao, & Turano, 2007; Yamamoto & Philbeck, 2013; *clinical*-Fortenbaugh, 2008) and physical mobility in general (Turano et al., 2004). While reduced peripheral field negatively impacts spatial memory for objects in a small-scale spatial array and also has detrimental effects on the physical act of mobility, not as much is known about the effects of reduced peripheral field on subsequent spatial memory after navigation in a novel environment.

Research has addressed the deficits of low vision at a sensory level (low-level perceptual research), a motor level (examining the physical act of mobility), and at a cognitive level (like the work described here). This project tested a hypothesis about the effects of visual impairment on navigation from a cognitive level in a previously established paradigm. This study had two related goals. The first was to define a range of restricted peripheral field that allows for/impairs spatial learning during navigation. For simulated peripheral field-loss, we tested different levels of restriction-severity to determine the range of restriction that may impair spatial memory. Observing this range in simulated peripheral field loss may give some indication of the deficits involved in different levels of clinical peripheral field loss. The second goal was to examine walking speed as a potential strategy that might be used to offload the cognitive costs of navigating with severely restricted peripheral field. With increasing peripheral field restriction, it is possible that participants adopt a slower walking speed to allow for improved capacity for spatial learning. This is important information for future work that may focus on developing interventions. A direct comparison of slow and fast walking speed helps to answer the question of whether slower walking speed is an effective strategy for improving spatial memory for navigation. The implications from this research are important to consider, as oftentimes people with low vision (and people in general) are in a situation where they must navigate through a new space and may need to remember the location of important landmarks for potential future use (i.e., a bathroom, a fire escape, etc.) or may need to have a global/survey representation of space for subsequent novel wayfinding.

CHAPTER 2

BACKGROUND

A fair amount of research has examined mobility and spatial memory behavior for individuals with blindness or low vision (early and late onset). One area of focus is strategy-use (see also Cornoldi, Tinti, Mammarella, Re, & Varotto, 2009; Tellevik, 1992; Gaunet, Martinez, & Thinus-Blanc, 1997; Gaunet & Thinus-Blanc, 1996). For example, Hill and Rieser (1993) observed search strategies for objects in a spatial layout in individuals with early- and late-onset blindness. Based on performance, they classified the “best” and “worst” performers and then observed the different strategies used by the two groups. They identified several different strategies through tracking of movement through the space and self-report from the participants. They found that the best performers effectively used systematic object-link search patterns, while the worst performers used more of an aimless wandering strategy. Thus, the best performers correctly identified the location of more targets in a shorter amount of time than the worst performers. This research suggests that individual differences play a significant role in search strategy and spatial memory.

In addition to the study of strategies for exploration, other research has examined the role of cognitive load in navigating with low vision. Rand, Creem-Regehr, and Thompson (2015) found that navigating and learning a new space with severely degraded viewing conditions (as compared to normal vision) had a negative impact on spatial memory of learned object locations. The same individual performed worse on a spatial memory task when he or she was wearing vision-degrading goggles compared to when he or she was wearing non-vision-degrading goggles. These goggles simulated extremely reduced visual acuity and contrast, similar to what might be experienced in an advanced stage of Macular Degeneration. Rand et al. (2015) proposed that this spatial memory impairment may be due in part to increased cognitive load during the task. When participants were navigating and learning the environment with degraded vision, they were slower to respond to a secondary auditory attention task than when they were using their normal vision. This suggests that navigating in a novel environment with simulated severe visual impairment relates to increased cognitive load, which may subsequently affect spatial memory.

Interestingly, Rand et al. (2015) conducted an additional experiment that compared the effect of guidance on spatial memory and attention in the same paradigm. With degraded vision in all conditions, they compared each individual's performance on the task when he or she was guided by the experimenter (held onto the experimenter's arm) to when the individual walked on his or her own. Participants performed better on both the spatial memory and attention task when guided, suggesting that a physical aid might potentially relieve some of the cognitive demands of navigating. These findings suggest that navigating with severely degraded acuity and contrast is detrimental for spatial memory, potentially because of limited cognitive resources. Under degraded vision conditions, participants may be devoting more of their attention to the physical challenge of safe mobility while navigating through the environment, rather than being able to allocate attention to the processes needed for spatial learning and memory. While the results from these studies suggest that visual acuity and contrast sensitivity may be an important part of successful spatial memory while navigating because of the attention required during mobility, a large body of research suggests that peripheral vision may also play an important role.

One such study even claims that peripheral field may be more important for mobility than both visual acuity and contrast. Turano et al. (2004) observed a significant correlation between the degree of the visual field and performance on two mobility tasks—namely, the greater the peripheral field loss, the slower the walking speed and the greater number of "bumps" into obstacles. The authors suggest that visual field may contribute a unique and necessary component to mobility, above and beyond both visual acuity and contrast sensitivity. In the Turano et al. (2004) study, visual acuity did not correlate with either walking speed or obstacle avoidance. Contrast sensitivity did not correlate with walking speed, but the authors did observe a significant correlation between contrast sensitivity and number of bumps.

In another comparison study of different types of vision loss, Rieser et al. (1992) tested individuals with early- and late-onset acuity and contrast impairment, early- and late-onset field loss, normal vision, and total blindness on a spatial memory task for object locations in the individual's respective neighborhood. They found that individuals with early-onset field loss had significantly more error in their spatial memory on a pointing task than any of the other low-vision groups. Interestingly, the early-onset field loss group actually performed even worse than the congenitally blind individuals. The authors propose a potential theory that addresses why the loss of peripheral vision at an early age may take such a significant toll on spatial memory. Rieser et al. (1992) suggest that broad-field vision is necessary at least in early life to develop nonvisual sensitivity; namely, the authors hypothesize that broad-field vision enhances one's ability to properly sync the biomechanical feedback provided by movement with "distances and directions moved relative to features fixed in the surrounding environment" (p. 220). This is an interesting theory that suggests that the detrimental effects of peripheral field loss for spatial learning may occur at a perceptual learning level, rather than affecting one's ability to construct or understand mental representations, for example. In sum, this paper suggests that peripheral field is an important aspect of at least the perceptual learning component of spatial learning.

Other research examining early vs. late onset of visual impairment suggests findings that conflict with what Rieser et al. (1992) concluded (for a review, see Cattaneo et al., 2008). For example, Monegato, Cattaneo, Pece, and Vecchi (2007) compared congenitally visually impaired individuals to people who acquired their visual impairment later in life on a task measuring visuospatial abilities for locations on two-dimensional (2-D) and three-dimensional (3-D) figures. They found that those participants with early onset visual impairment outperformed those with late onset impairment. They suggest that the difference may be due to the development of compensatory mechanisms for the early-onset individuals (i.e., they have had more experience with the visual impairment and have developed compensatory mechanisms accordingly). Thinus-Blanc and Gaunet (1997) reviewed the related literature on the topic of early- vs. late-onset visual impairment and pose potential explanations for the disparity in the research findings. For example, one potential explanation for the difference in findings may be attributed to significant differences in the tasks (i.e., testing memory for spatial locations on 2-D and 3-D figures vs. testing spatial memory for familiar environments). Thinus-Blanc and Gaunet (1997) pose that it may be more useful to examine and understand the different *strategies* that people with visual impairments use, rather than focusing on age of onset and other external factors.

Although some of the results are conflicting, the findings from these studies do suggest the importance of examining different types of vision loss and how they relate to mobility. It appears that not all types of vision loss have the same effect when it comes to navigating through a space. While it is clear that the literature seems to suggest an important role for peripheral field for mobility in general and memory for locations in familiar environments, it is also important to consider the role for spatial learning during navigation itself.

Research suggests that peripheral field loss *does* have a negative effect on spatial memory for object locations, at least with regards to memory for objects viewed from a single static viewpoint. Yamamoto and Philbeck (2013) found that viewing a small-scale spatial layout from a single viewpoint with simulated field loss (10˚) resulted in more memory distortions than viewing the layout with a wide field-of-view. The authors suggest that restricted peripheral vision may impair spatial memory because it affects some part of the memory process—encoding, maintenance, or retrieval. They tested the theory that one of the important components of peripheral vision is that it allows for the opportunity for eye movements. They suggest that eye movements (rather than the peripheral field itself) may be what contribute to accurate and efficient spatial learning, since eye movements allow the viewer to quickly detect and perceive a wide area of space. Indeed, Brockmole and Irwin's (2005) finding that eye movements are involved with encoding of dynamic spatial arrays (as opposed to static displays) also provides evidence for this idea.

Not only do eye movements reduce the potential negative effects of restricted peripheral field, but it seems, so does bodily movement. The Yamamoto and Philbeck (2013) study is limited because it only examines encoding and retrieval for objects viewed from a stationary viewpoint. Another line of research examines how physically moving to the targets while under visual field restriction affects spatial memory. Fortenbaugh, Hicks, Hao, and Turano (2007) measured the effect of simulated restricted peripheral field on memory for spatial locations. In an immersive virtual small-scale space, participants viewed a series of simultaneously presented targets and were instructed to walk to each target from the starting location on a predetermined path. For the testing phase, the targets disappeared and the participants were instructed to walk to the remembered location of each target and pause. The findings showed a significant negative relationship between peripheral field restriction and spatial location error. Namely, as field restriction increased (i.e., the size of the field-of-view got smaller), error for the location of the objects increased.

In an additional experiment, Fortenbaugh, Hicks, Hao, and Turano (2007) examined the impact of movement on encoding under the different field restrictions. Participants either viewed the targets from a single stationary position or walked to the targets and back as in the previous experiments. The findings showed that no movement (the stationary viewpoint) negatively affected the compression of space most strongly for participants in the 10° vision condition. This suggests that perception of distance is not as impaired by peripheral field loss if the individual is still able to move around in the space.

The authors conclude by suggesting that peripheral field is important for spatial cognition/perception because it allows the viewer to understand the global space, which serves as a framework for perceiving individual components. When peripheral field is limited, the spatial framework is impaired, causing the viewer to "extrapolate" more of the environment. These estimates may not encompass change in the environment, which could potentially explain the spatial distortions and memory error.

In a similar experiment, Fortenbaugh, Hicks, and Turano (2008) observed spatial distortions for participants with actual peripheral field loss of a spatial layout. They studied individuals diagnosed with Retinitis Pigmentosa (RP) of different levels of severity in a small-scale spatial layout task. In both virtual and real-world versions of the experiment, participants first navigated to targets on a predetermined path and then back to the starting position. The testing phase required participants to navigate from the starting position to where they remembered the target to be (with the target removed). Researchers again observed a negative relationship between peripheral field loss and spatial memory for the layout. As peripheral field loss became more severe, placement error of the targets increased. Fortenbaugh et al. (2008) suggest that the errors may be explained in part by distance underestimation in the majority of participants.

These findings motivated our current series of studies that examine how field loss affects spatial memory and attention. While the research discussed above suggests that field loss impacts mobility and/or spatial memory for static spatial layouts, objects in small-scale spaces, and landmarks in familiar environments, the proposed work will examine how peripheral field loss impacts both mobility and spatial memory for landmarks during a navigation task in a novel environment. Visual impairments may affect spatial memory for navigation at the encoding, storage, or retrieval stage of memory. For example, it may be the case that visual impairments affect perceptual encoding (e.g., causing distortions in the way the space is perceived) or cognitive encoding of the space (e.g., by demanding the use of limited cognitive resources (attention) and thus limiting the potential for proper encoding. The current studies attempt to explain *why* visual impairment negatively affects spatial memory by testing the effects of vision loss on encoding at the cognitive level.

CHAPTER 3

GENERAL METHOD

3.1. Overview

The following experiments use the method described in Rand, Creem-Regehr, and Thompson (2015) by using a real-world navigation task with predetermined paths. Spatial memory for landmarks was assessed using a pointing task.

3.2. Materials

For Experiments 1-3, all participants wore two sets of goggles throughout the experiment. Both were welding goggles with the original plastic lenses removed. The fields-of-view of each set of goggles were restricted in one eye using black cardstock paper with the appropriate-sized hole cut out of the center of the circle. The non-dominant eye was covered completely. Two sets of goggles were created for each vision condition (small and wide) with the aperture in the dominant eye (i.e., a right and left small aperture and a right and left wide aperture). As a manipulation check of the peripheral-field-restricting goggles, we conducted an aperture test. During training, participants wore each set of goggles and were instructed to walk toward a black circle on the wall and stop as soon as the circle filled their entire peripheral vision. The black circle on the wall was placed at the participant's eye height. The distance from the target at which the participant stopped (i.e., the distance at which the circle "filled the participant's vision") was used to calculate the degree of field-of-view that the participant perceived (see Appendix A for results of all vision tests).

To measure cognitive load, participants completed a secondary reaction time task simultaneously throughout the encoding portion of each path. Research suggests that reaction time measures indicate level of cognitive load—slower reaction times indicate greater cognitive load (Verway & Veltman, 1996). As such, throughout all experiments, participants completed a secondary, auditory reaction time task. Tones were randomly generated from a laptop carried by a second experimenter, and participants were instructed to respond as quickly as possible to the tone by clicking a cordless mouse. Participants wore wireless headphones throughout the experiment. Responses to the tones were recorded on the laptop. At the end of each path, after completing the memory recall task, participants referenced the Subjective Units of Distress Scale (SUDS) to make judgments about how calm or anxious they felt while completing each trial (Bremner et al., 1998). At the end of the experiment, participants were asked to fill out the Davidson, Dixon, and Hultsch's (1991) Memory Anxiety Questionnaire and the Santa Barbara Sense of Direction Scale (Hegarty, Crookes, Dara-Abrams, & Shipley, 2010).

3.3. Participants

Participants were recruited for all experiments from either the University of Utah psychology participant pool or from the broader community. University of Utah students were compensated with partial course credit and participants from the broader community were paid $10 as compensation for their time. All participants had normal or corrected to normal vision and walked without impairment. See Appendix A for individual acuity values.

3.4. Procedure

The following experiments took place in the Merrill Engineering Building on the University of Utah campus, a building that was novel to the majority of our participants. Familiarity with the environment was assessed by an additional question added to the end of the Santa Barbara Sense of Direction Scale that asked participants to rate their familiarity with the environment on a 7-point Likert scale. For Experiment 1, 97% of participants indicated a 6 or a 7 (strongly disagree) with the statement “I have a lot of experience with the Merrill Engineering Building.” For Experiment 2, 89% indicated 6 or 7. For Experiment 3, 93% indicated 6 or 7. For Experiment 4, 90% indicated 6 or 7. Across all four experiments, 92% indicated 6 or 7. Thus, paths and landmarks were novel for the vast majority of participants. Each of the four paths was unique, such that there was no crossover from one path to another and the participant was not exposed to the same paths or landmarks more than once. For Experiments 1-3, vision condition was manipulated within-subjects, such that all participants completed two paths in the reduced vision condition and two paths in the “normal” vision condition. The order of the vision condition was manipulated between subjects, such that half of participants completed the paths in a restricted-normal-restricted-normal order, and the other half of participants completed the paths in a normal-restricted-normal-restricted order. Vision order was randomly assigned.

Upon arrival, participants signed a consent form and filled out demographics information. Then they were given an eye exam to assess for normal or corrected-to-normal visual acuity. Any participants who did not have normal or corrected-to-normal 20/20 vision were debriefed and dismissed from the experiment (although none of the participants fell into this category in any of the experiments). Next, participants completed a dominant eye test. Each individual was instructed to hold a black sheet of paper with a 2 inch diameter circle cut out of the center and look through the hole at a spot in the room. They were then asked to close one eye and then the other to determine for which eye the spot on the wall disappeared from their vision. In whichever case the target appeared to “move” out of the circle, that eye was determined to be the dominant eye. For the rest of the experiment, participants were required to use only their dominant eye.

Participants were then trained on the secondary, auditory attention task. Participants listened through wireless headphones to a series of randomly generated tones that occurred every 1-6 seconds. They were instructed to respond to each tone by clicking a cordless mouse as quickly as possible after hearing the tone. Tones were generated and responses were recorded on a laptop carried by a second experimenter throughout the experiment. During the practice, the volume of the tones was adjusted to suit the participant’s comfort.

Participants walked 4 paths with 3 landmarks each. Using the general method described here, Experiments 1-3 compared restricted vision of the dominant eye to the normal vision condition (the natural field-restriction of wearing the goggles (~60˚)). Participants walked along the paths following verbal instructions from the experimenter, who maintained position on the side opposite the participant’s dominant hand and slightly behind the participant. The experimenter assured each participant that she would do her best to maintain the safety of the participant (i.e., not letting him or her run into walls or objects, etc.). The experimenter stopped the participant at each landmark and verbally described the location of the landmark (e.g., “Stop here. On your left is a water fountain”). After a 3-second pause, the experimenter encouraged the participant to continue walking. Throughout each path, participants completed an auditory attention task that consisted of listening through wireless headphones to randomly generated beeps that occurred every 1-6 seconds. Participants responded by clicking a cordless mouse as fast as possible after each beep.

To measure spatial memory, we used the verbal-pointing measure described by Philbeck, Sargent, Arthur, and Dopkins (2008). At the end of each path, participants indicated the location of each landmark as probed by the experimenter by pointing directly to the landmark. Participants were instructed to point directly to the landmark from the final location, as if they could see straight through the walls right to the landmark. Participants were also instructed to indicate the quadrant and degree location of the landmark from an egocentric perspective. The participants were instructed to imagine that they were standing at the center of four quadrants and that the landmark could be located at any spot within the quadrants around them (e.g., front-left, front-right, back-left, or back-right with a range from 0-90˚ in each quadrant; see Figure 3.1). Participants were instructed during practice that memory for the landmark locations would be probed in random order (not in the same order that they were encountered on the path).

Participants were then asked to rate their level of self-reported anxiety on the Subjective Units of Distress Scale for the path on average, when turning corners, and when encountering people. Finally, participants completed 1 minute of the auditory attention task while standing stationary to establish a baseline reaction time for each path.

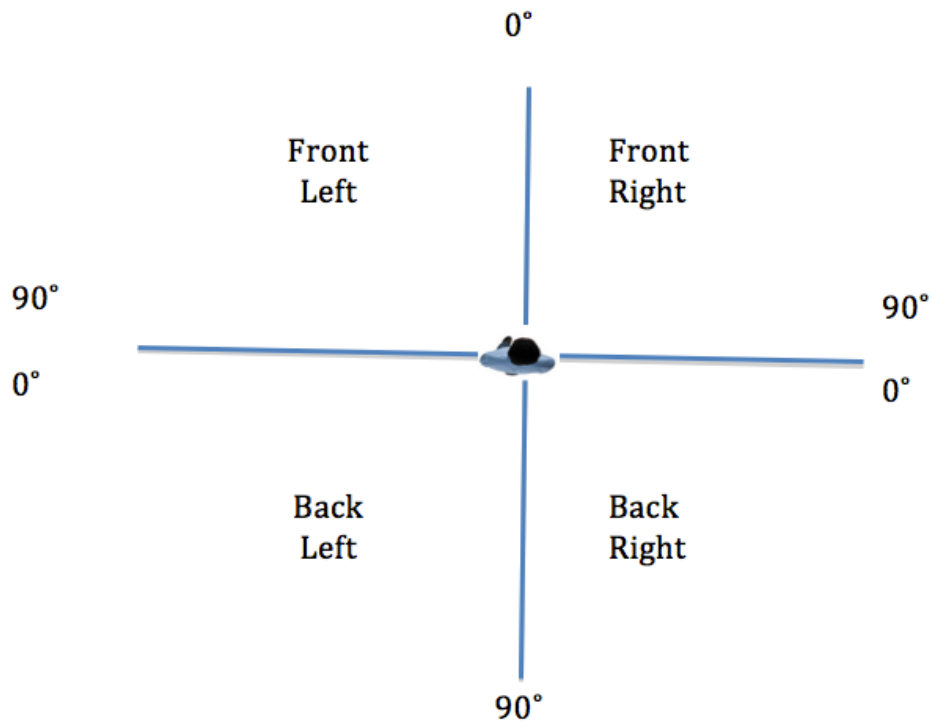

Figure 3.1. Illustration of the Degree-Quadrant Pointing Task (Philbeck, Sargent, Arthur, & Dopkins, 2008).

This procedure was repeated for the remaining 3 paths. After completing the 4 paths, participants filled out the two surveys. Finally, they were then debriefed, thanked, and dismissed.

3.5. Design and Data Analysis

Experiments 1-3 used a 2 x 2 (Vision Condition x Vision Order) design. Vision condition was manipulated within-subjects, such that all participants completed two paths in the reduced vision condition and two paths in the "normal" vision condition (~60˚ monocular field-of-view). The order of the vision condition was manipulated between subjects, such that half of participants completed the paths in a restricted-normal-restricted-normal order, and the other half of participants completed the paths in a normal-restricted-normal-restricted order. Vision order was randomly assigned. Data were analyzed for all studies using 2x2 repeated measures Analyses of Variance (ANOVAs) in the SPSS statistical software. This allowed us to directly compare the two different vision conditions for the same individual.

CHAPTER 4

EXPERIMENT 1

Clinical and simulated vision loss research suggests that peripheral field loss negatively impacts navigation when the field loss is extreme. For example, Hassan, Hicks, Lei, and Turano (2007) claim that the critical field size for efficient navigation in a virtual environment depends on the image contrast levels of the environment. They attempted to determine the minimum peripheral field diameter necessary for efficient navigation (defined by walking speed and obstacle avoidance). In their studies, the critical points were 32.1˚ for low image contrast levels, 18.4˚ for medium, and 10.9˚ for high. In their study of clinical low-vision patients, Fortenbaugh, Hicks, and Turano (2008) observed a significant negative relationship between peripheral field loss and placement error for remembered object locations. As the field-of-view of clinical patients decreased from 20˚ to 10˚ and smaller, the mean placement error for the remembered objects increased. These findings motivated us to examine peripheral field loss at a moderately extreme restriction of 15˚. We suspected that limiting the peripheral vision to 15˚ would demonstrate a similar impairment to that reported by the studies mentioned above.

Experiment 1 examined the effect of simulated restricted field of view of 15˚ on spatial memory for navigation. Since less of the global space of the changing environment could possibly be encoded, we hypothesized that an individual would perform worse on the spatial memory task after encoding the environment in the restricted field condition compared to the "normal" condition. Experiment 1 also tested a theory that could explain this spatial memory impairment. Rand et al. (2015) hypothesized that the spatial memory impairment may be partially a result of increased cognitive load during navigation with restricted vision. This was tested through a secondary attention task that is described in the general methods above.

4.1. Method

Thirty-two University of Utah undergraduates were recruited from the psychology subject pool to participate in Experiment 1 for partial course credit (9 male, 23 female). Data from one participant were removed because of a recording error during the attention task. Participants walked 4 paths with 3 landmarks each. Using the general method described above, Experiment 1 compared a mildly severe field restriction (observed 17.8˚) of the dominant eye to the monocular "normal vision condition" (the natural field-restriction of wearing the goggles (observed 67.7˚)). See Appendix A for individual simulated FOV values.

4.2. Results and Discussion

Results from Experiment 1 indicate no difference in average absolute error or reaction time between vision conditions. Absolute error was calculated as the absolute value of the difference between the pointing vector and the correct vector. A mixed-design analysis of variance (ANOVA) with vision condition as a within-subjects variable and vision order as a between-subjects variable revealed that absolute error for the 15˚ FOV condition (M=25.96˚, SE=2.86˚) did not differ significantly from error for the 60˚

FOV condition (M=27.16˚, SE=2.81˚), $F(1, 30) = .233$, $p = .633$, η_p^2=.008 (see Figure 4.1). A separate mixed-design ANOVA suggested that there was no significant difference in reaction time between the 15˚ condition (M=.589, SE=.03) and the 60˚ FOV condition (M=.583, SE=.02), $F(1, 30) = .197$, $p = .660$, η_p^2=.007. A third mixed-design ANOVA examining the self-reported anxiety (SUDS) experienced by participants in the different vision conditions does suggest a significant difference between vision condition, $F(1, 30) = 37.924$, $p < .001$, η_p^2=.558. Navigating with 15˚ restricted FOV (M=31.83, SE=3.66) does appear to cause significantly more anxiety than navigating with wide FOV (M=19.47, SE=2.83). Thus, it appears that participants experience the two vision conditions differently at least on an affective level, but this difference in experience may not be at the cognitive level.

Experiment 1 tested two hypotheses. First, we hypothesized that a severe peripheral field restriction (15˚) would negatively affect spatial memory compared to a less extreme restriction (60˚). Second, we hypothesized that the 15˚ restriction would

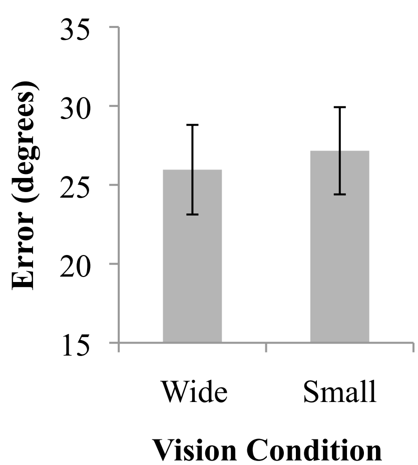

Figure 4.1. Absolute pointing error results from Experiment 1. Error bars represent +/- 1 standard error (SE) of the mean.

increase cognitive load while navigating compared to the less extreme restriction. There are several potential explanations that may explain why we did not observe the expected effects. Perhaps the participants were still able to move their heads (and thus also their eyes) in a manner sufficient to encode enough of the dynamic spatial layout of the hallways at any given instant. Alternatively, perhaps the 15˚ restriction still allowed for the accurate development of a mental representation of the global layout. Since the participants were still able to move their heads, they may have been able to detect changes in the moving layout and match those changes with their own movement (see Rieser et al., 1992). Finally, the visual degradation at this level may not have been severe enough to impair encoding of the spatial representation needed for spatial learning during this task. Indeed, our results show that restricting the peripheral field to 15˚ does not appear to require additional attentional resources for effective navigation and spatial learning (as shown through no difference on RT). This suggests that participants were able to navigate and remember spatial locations just as well in both vision conditions, and that the act of being mobile did not require more monitoring in one condition compared to the other. Some research suggests that spatial memory for wayfinding may not be impaired by simulated peripheral field loss until that field loss reaches an extreme level. In an unpublished honors thesis, Mason (2014) tested three different field restrictions and observed a gradual decline in performance from 20˚ to 10˚ and a sharp drop in performance once restriction reached 4˚. Indeed, even with clinical patients, Fortenbaugh et al. (2008) observed the strongest effect on spatial memory for the patients with less than 10˚ of their visual field. Thus, simulating 15˚ of the peripheral field-of-view may be sufficient for our participants to navigate, remember spatial locations, and use cognitive resources as they do with normal vision.

CHAPTER 5

EXPERIMENT 2

Contrary to our hypothesis in Experiment 1, we did not observe a negative impact on spatial memory for the restricted FOV condition as compared to the wide FOV condition.

As mentioned above, it is possible that having available 15˚ of the central field is enough to effectively navigate in our fairly high-contrast environment. To address this possibility, we conducted Experiment 2 to examine a more severe peripheral field restriction. Thus, Experiment 2 tests the hypothesis that a FOV of 10˚ should negatively impact spatial memory during navigation. Our second hypothesis is that the spatial memory impairment may be related to increased cognitive load.

5.1. Method

Twenty-eight participants were recruited from the psychology subject pool and the broader community to participate in this study for partial course credit or monetary compensation (17 females). None of the participants had taken part in Experiment 1. In Experiment 2, the aperture on the welding goggles was made smaller to simulate a more severe loss of peripheral field-of-view. The monocular field-of-view for Experiment 2 averaged 11.14˚. The monocular field-of-view for the control condition averaged 64.45˚. See Appendix A for individual simulated FOV values. The procedure was the same as in

Experiment 1. Participants walked the same 4 paths as in Experiment 1 with the same 3 landmarks each.

5.2. Results and Discussion

Results from Experiment 2 indicate no difference in average absolute pointing error between vision conditions. A mixed-design analysis of variance (ANOVA) with vision condition as a within-subjects variable and vision order as a between-subjects variable revealed that error for the 10˚ FOV condition (M=20.75˚, SE=1.64˚) did not differ significantly from error for the 60˚ FOV condition (M=19.74˚, SE=1.66˚), $F(1, 26) = .384$, $p = .541$, η_p^2=.015. A separate mixed-design ANOVA suggested that there was a significant difference in reaction time ($F(1, 26) = 11.91$, $p < .01$, η_p^2=.314) between the 10˚ condition (M=.644, SE=.012) and the 60˚ FOV condition (M=.619, SE=.013). This suggests that participants are under a significant amount of cognitive load when navigating with the 10˚ goggles (see Figures 5.1 and 5.2). A third mixed-design ANOVA examining the self-reported anxiety (SUDS) experienced by participants in the different vision conditions suggests a significant difference between vision condition ($F(1, 26) = 45.578$, $p<.001$, η_p^2=.637). Navigating with 10˚ restricted FOV (M=34.07, SE=3.52) does appear to cause significantly more anxiety than navigating with wide FOV (M=19.42, SE=2.63). Thus, it appears that participants experience the two vision conditions differently, and navigating with the field restriction of 10˚ requires more cognitive resources. Interestingly, the 10˚ condition appears to be affecting participants' cognitive performance, but not to the extent that it impairs spatial memory.

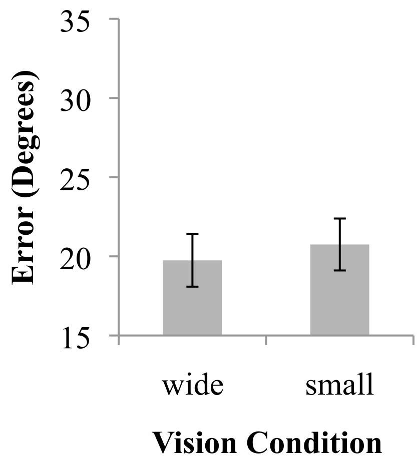

Figure 5.1. Absolute pointing error results from Experiment 3. Error bars represent +/- 1 standard error (*SE*) of the mean.

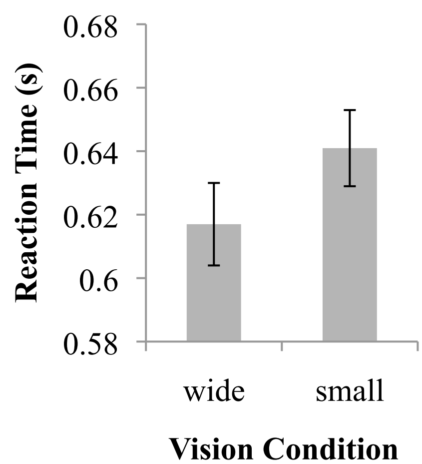

Figure 5.2. Reaction time results from Experiment 3. Error bars represent +/- 1 standard error (*SE*) of the mean.

CHAPTER 6

EXPERIMENT 3

As with the results from Experiment 1, it is possible that the field restriction of 10˚ in Experiment 2 was not extreme enough to impact the individual's normal head scanning strategies or overall encoding of the dynamic spatial layout. Experiment 3 tested the hypothesis that restricting the peripheral field to a very extreme level of 4˚ would significantly impair spatial memory for navigation, and that this impairment may be related to increased cognitive load.

6.1. Method

Twenty-eight University of Utah undergraduates were recruited from the psychology subject pool to participate for partial course credit. The materials were exactly the same as in the first two experiments with one exception. The goggles were adjusted to achieve a monocular field-of-view around 4˚. To do this, each set of goggles was updated with a 2.5-inch cone on the covering of the dominant eye. The aperture was cut out of the far end of the cone. The monocular field-of-view for the more severely restricted condition averaged 4.44˚. The monocular field-of-view for the control condition averaged 62.78˚. See Appendix A for simulated FOV values. The procedure followed that of Experiments 1 and 2. Participants walked the same 4 paths as in the previous experiments with the same 3 landmarks each.

6.2. Results and Discussion

Results from Experiment 3 indicate a main effect of vision condition for absolute pointing error. A mixed-design analysis of variance (ANOVA) with vision condition as a within-subjects variable and vision order as a between-subjects variable revealed that pointing error for the 4˚ FOV condition (*M*=30.93˚, *SE*=3.54˚) differed significantly ($F(1, 26) = 7.16$, $p<.05$, $\eta_p^2=.216$) from error for the 60˚ FOV condition (*M*=22.21˚, *SE*=1.28˚). A separate mixed-design ANOVA suggested that there was a significant difference ($F(1, 26) = 8.26$, $p <.01$, $\eta_p^2=.241$) in reaction time between the 4˚ condition (*M*=.642, *SE*=.013.) and the 60˚ FOV condition (*M*=.621, *SE*=.014), suggesting that participants are under a significant amount of cognitive load when navigating with the 4˚ goggles (see Figures 6.1 and 6.2). A third mixed-design ANOVA examining the self-reported anxiety (SUDS) experienced by participants in the different vision conditions revealed a significant difference between vision condition ($F(1, 26) = 51.30$, $p<.001$, $\eta_p^2=.664$). Navigating with 4˚ restricted FOV (*M*=40.46, *SE*=3.87) appears to cause significantly more anxiety than navigating with wide FOV (*M*=17.54, *SE*=2.23). Thus, again, it appears that participants experience the two vision conditions differently, and at a FOV of 4˚, the difference may be experienced at the cognitive level.

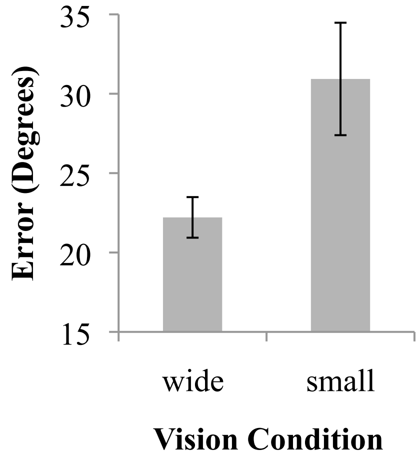

Figure 6.1. Absolute pointing error results from Experiment 3. Error bars represent +/- 1 standard error (*SE*) of the mean.

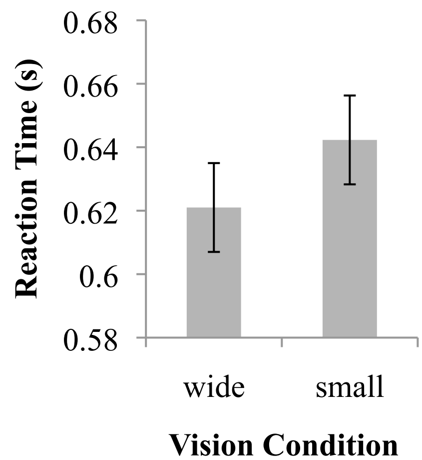

Figure 6.2. Reaction time results from Experiment 3. Error bars represent +/- 1 standard error (*SE*) of the mean.

CHAPTER 7

EXPERIMENT 4

Results from Experiments 1-3 suggest that peripheral field restriction does not impair spatial memory for navigation until the restriction is very severe. Our unexpected findings in Experiments 1 and 2, that showed no spatial memory impairment at 15˚ and 10˚ FOVs, motivated an examination of strategy use in Experiment 4. Since participants did so well on the spatial memory task with severe FOV restriction, we hypothesized that participants may have been knowingly or unknowingly implementing strategies to potentially offload the demands of the task. One such strategy may have been to slow down one's own speed of walking. In Experiments 1-3, we encouraged participants to walk at a pace that felt comfortable to them and we did not control walking speed across the four paths. Post-hoc analyses of the walking speeds in each experiment showed that participants walked significantly slower in the severely restricted peripheral field condition compared to the 60˚ condition. Specifically, in Experiment 1, participants walked significantly slower in the 15˚ condition (M=149.434 s, SE=4.45) compared to the 60˚ condition (M=133.963 s, SE=3.17), $F(1, 29)=18.429$, $p<.001$, $\eta_p^2=.389$. In Experiment 2, participants walked significantly slower in the 10˚ condition (M=175.78 s, SE=4.89) compared to the 60˚ condition (M=141.581, SE=2.86) $F(1, 26)=115.18$, $p<.001$, $\eta_p^2=.816$. In Experiment 3, participants walked significantly slower in the 4˚ condition (M=197.94 s, SE=10.33) compared to the 60˚ condition (M=145.97, SE=4.07),

$F(1, 26)=41.04$, $p<.001$, $\eta_p^2=.612$. As such, it is possible that participants slowed down during the severe restriction vision condition in a way that effectively freed up the attention needed for mobility monitoring during the task. This attention may have then been devoted to components of the memory task. This is one possible explanation as to why participants did just as well on the spatial memory task in both vision conditions.

Indeed, research shows that people (older adults in particular) adopt a slower walking speed, especially in cases where cognitive demand is high. For example, Kelly, Schrager, and Price (2008) found age-associated changes in gait speed and stability for narrow-based walking, such that as age increases, walking speed and stability decrease. Interestingly, the addition of a simultaneous cognitive task resulted in decreased speed across all age groups, but had no effect on stability. Importantly, the older adults in this study were healthy with no history of falls. The authors pose that healthy older adults may effectively adopt a slower walking speed as a compensatory mechanism to maintain stability while completing simultaneous cognitive and physical tasks (effective mobility monitoring). Similarly, Alexander, Ashton-Miller, and Giordani (2005) found that both younger and older adults completed a Trail-Making-Task more slowly when completing a simultaneous cognitive task compared to when they completed the physical task alone. However, older adults were more strongly affected by the simultaneous cognitive task compared to younger adults (i.e., performance time was longer). Taken together, these findings suggest that people may knowingly or unknowingly adopt a slower walking speed to offload the cognitive demands of simultaneously navigating and completing cognitive tasks.

Experiment 4 tested the hypothesis that the slower walking speed naturally adopted by participants during a task would relate to better spatial memory compared to a manipulated faster walking speed. Our second hypothesis was that walking slower also frees up more cognitive resources (measured by the same auditory reaction time task as in Experiments 1-3). We chose to use the 10˚ FOV restriction because results from Experiment 2 suggest that navigating with 10˚ FOV demands the use of more cognitive resources but does not impair spatial memory. We wanted to test the possibility that participants were implementing a slower walking speed strategy in Experiment 2 that effectively helped in offloading the cognitive demands of navigating with restricted peripheral field.

7.1. Method

Twenty-eight University of Utah undergraduates were recruited from the psychology subject pool to participate for partial course credit. Five participants were run as practice subjects for the experimenters and were not included in the analyses. The materials were the same as in the first three experiments. The 10˚ goggles were used for all paths in this experiment. The monocular field-of-view for the goggles averaged 12.02˚. See Appendix A for individual simulated FOV values. The procedure was similar to that of Experiments 1-3, with several important differences described below. Participants walked the same 4 paths as in the previous experiments with the same 3 landmarks each, although the order of the paths was manipulated differently.

7.2. Design and Procedure

Experiment 4 used a 2 x 4 (Walking Speed Condition x Path Order) design. The 4 paths used in Experiment 4 were the same as in Experiments 1-3. We manipulated the order of the paths, so that each pairing of long and short paths was counterbalanced. Two of the experimental paths are longer and 2 of the paths are shorter, and we wanted to make sure that any of the effects of walking speed that we observed were not attributed to path length alone. Thus, there were 4 path orders and participants were randomly placed in one of the four order conditions. Walking speed condition was manipulated within subjects, such that all participants completed the first 2 paths with no instruction about walking speed and the second 2 paths at a faster pace after a faster walking speed training. Walking speed condition was not counterbalanced, as we did not want participants to be made aware of walking slower (since we hypothesized that they were adopting the slower pace as a helpful strategy). Data were analyzed for all studies using 2x4 repeated measures Analyses of Variance (ANOVAs) in the SPSS statistical software. This allowed us to directly compare the two different walking conditions for the same individual.

Two experimenters with stopwatches measured path time. Timers began as soon as the participant began walking and ended as soon as the participant was instructed to stop at the end of the path. The average path time across the two measures was used in a manipulation check[1]. A repeated measures ANOVA with path order as a between-subjects measure and walking speed as a within-subjects variable provides support for the effectiveness of our manipulation. As measured by the average of the two recorded times, participants walked significantly slower in the first 2 paths (M = 173.99 s, SE = 4.38) than in the second 2 paths after receiving the training (M = 127.73 s, SE = 2.63), F(1, 22)

[1] For 6 of the participants, only one path time was recorded for all paths. For 8 participants, only one path time was recorded on 2 of the paths because of experimenter error. Instead of averaging the two recorded path times, in these cases the single recorded time was used in the manipulation check. For 2 of the participants, no path time was recorded on one of the paths. These 2 cases were not included in the analysis of the walking speed manipulation.

$= 158.507$, $p < .001$, $\eta_p^2 = .88$.

Upon arrival, participants completed the same preparatory materials, vision tests, and training as in Experiments 1-3. They did not receive any instruction about walking speed. Participants walked 4 paths with 3 landmarks each in the path orders described above, all with the restricted 10˚ FOV. As in the prior experiments, throughout each path, participants completed an auditory attention task that consisted of listening through wireless headphones to randomly generated beeps that occurred every 1-6 seconds. Participants responded by clicking a cordless mouse as fast as possible after each beep.

7.3. Speed Training

After the first 2 paths, participants were led to a designated area in the building to complete the speed training. The lead experimenter instructed participants to follow along at the pace set by the experimenter. The experimenter walked 15.4 m in 11 seconds, equivalent to the average (or “preferred”) walking pace of 1.4 m/s (see Browning, Baker, Herron, & Kram, 2006). After the first demonstration by the experimenter, the participant was then asked to lead the experimenter at the same pace. He or she was timed, the time was recorded, and the participant was given feedback. The practice was repeated again with an additional question at the end of the path measuring the naturalness of walking at that pace on a 7-point Likert scale. The practice path was repeated with the goggles, and the same naturalness scale was measured at the end of the path.

Once the participant completed the training, the experimenter completed the final 2 paths, encouraging the participant to maintain the practiced, faster pace.

7.4. Results and Discussion

Results from Experiment 4 indicate no effect of walking speed on absolute pointing error. A mixed-design analysis of variance (ANOVA) with walking speed condition as a within-subjects variable and path order as a between-subjects variable revealed that pointing error for the slower walking speed condition (*M*=31.93˚, *SE*=2.49˚) did not differ from error for the faster walking condition (*M*=30.18˚, *SE*=2.79˚), $F(1, 24) = .579$, $p = .454$, η_p^2=.024. Interestingly, a separate mixed-design ANOVA suggested that there was a significant difference ($F(1, 24) = 23.83$, $p < .001$, η_p^2=.498) in reaction time between the natural, slower condition (*M*=.596, *SE*=.01.) and the faster condition (*M*=.639, *SE*=.013). This may suggest that participants are under a greater amount of cognitive load when walking at a faster pace (see Figures 7.1 and 7.2). A third mixed-design ANOVA examining the self-reported anxiety (SUDS) experienced by participants in the different vision conditions revealed a significant difference between walking condition, $F(1, 24) = 5.39$, $p<.05$, η_p^2=.183. Navigating at a faster walking pace (*M*=39.47, *SE*=3.36) appears to cause significantly more anxiety than navigating at a slower pace (*M*=33.95, *SE*=2.47). Thus, it appears that walking faster increases cognitive load, but does not affect spatial memory compared to walking at a chosen slower speed.

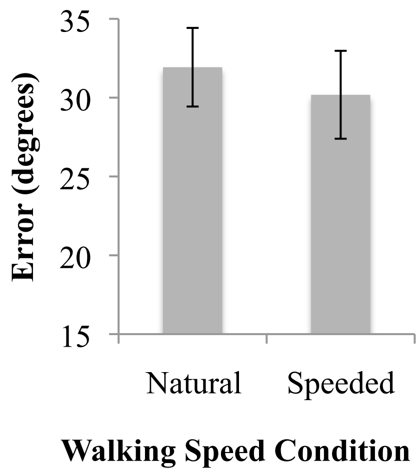

Figure 7.1. Absolute pointing error results from Experiment 4. Error bars represent +/- 1 standard error (*SE*) of the mean.

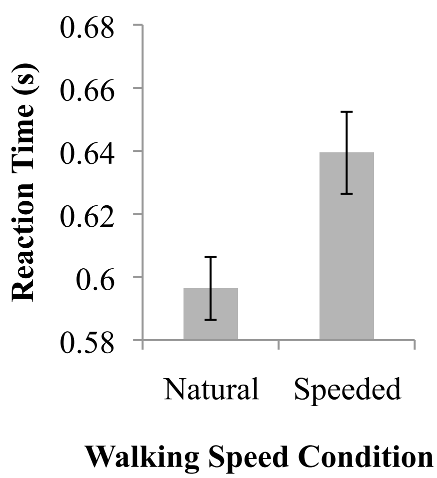

Figure 7.2. Reaction time results from Experiment 4. Error bars represent +/- 1 standard error (*SE*) of the mean.

CHAPTER 8

GENERAL DISCUSSION

Across the four experiments, our results suggest that simulated peripheral field loss has a negative impact on spatial memory for navigation, but only when that restriction reaches a very severe level (4˚). This impairment may be explained by two possible mechanisms that likely impact each other. First, the spatial memory impairment may come as a result of limited visual information during encoding. Research shows that restricting the peripheral field to an extreme level does have effects on spatial encoding. Evidence for this comes from studies that show that greater field restriction (less available visual information) negatively affects viewers' spatial memory for objects seen from a single viewpoint (see Yamamoto & Philbeck, 2013). Similarly, Fortenbaugh (2007) argued that limited peripheral field negatively affects the viewers' visual understanding of the global space because the visual restriction requires the viewer to extrapolate more of the environment, potentially resulting in an incomplete representation of the space. In order to process the scene in a way that is equivalent to how one would with normal vision while wearing the field-restricting goggles, one must incorporate more full-head movements in order to fixate on useful visual information. That being said, the object locations and interobject relations in the environment may not be integrated in the same way as they would with normal vision, which may result in a disconnected scene (or at least an environment that would take longer to process to reach equivalent understanding). It seems clear that limiting the visual information such that the entire scene cannot be processed at once has an impact on the ease and accuracy of memory encoding.

Importantly, the field restrictions used, and their effects on performance, relate to the limits of foveal vision. While the 15˚ and 10˚ goggles both allow for at least some peripheral vision to be potentially used along with central, or foveal vision, the 4˚ goggles may have limited the peripheral field entirely. The foveal centralis has a field-of-view of about 5˚ (Millodot, 2014), thus potentially requiring our participants to rely solely on foveal vision rather than on some combination of central and peripheral vision in the 4˚ condition. As such, participants may have been required to put forth more effort to maintain the object in sight in the 4˚ goggles, which may have altered cognitive load in a different way than the demands imposed by mobility monitoring.

The studies described here differ from the research mentioned above because of the nature of the type of large-scale environment used. Unlike many of the previous studies conducted in single room-sized spaces where configurations of objects could be perceived from a single viewpoint with eye and head movements, our studies required walking along paths to learn a configuration. Fortenbaugh and colleagues (2007) argue that the peripheral field loss related spatial memory detriment occurs because of the limited visual information itself (i.e., more extrapolation) and Yamamoto and Philbeck (2013) argue that spatial memory impairment is related to limited eye movements. We did not use a paradigm that could directly test these accounts because our configuration of objects could not be learned by vision alone. Rather, participants had to rely on additional information from their own navigation through the space to form a representation of the configuration. Thus, our task adds an additional factor—beyond limited peripheral field—namely, the need to monitor one's own mobility while walking with reduced visual information. The concept of mobility monitoring is very relevant for peripheral-field loss, as Turano and colleagues (2004) observed negative effects of field loss on physical mobility (i.e., less stability and decreased ability to avoid obstacles). The act of mobility seems to be more challenging when the mover has limited peripheral field, suggesting that peripheral field is important for mobility. As such, when peripheral field is restricted, demands for safe mobility might increase.

Taken together with the current studies, we argue that spatial learning is impaired during navigation with simulated visual impairment because of the increased *cognitive demands* (not necessarily the lack of visual information itself per se). The added effort for encoding with a visual restriction (i.e., more head movements needed to integrate views of the space) likely contributes to higher cognitive load. In addition, the physical act of mobility poses its own demands irrespective of vision condition (although highly affected by the presence or absence of visual information for most people). Results from Rand, Creem-Regehr, and Thompson (2015) showed that spatial learning during navigation with severely degraded acuity and contrast was impaired because of the increased cognitive load required for safe mobility monitoring. Their within-subjects design examined the effect of physical guidance on spatial memory and reaction time, tested in the same way as in the current studies. Results show that reducing the demands of safely navigating the environment (by providing a guide) helps to offload cognitive costs in a way that assists spatial learning. This suggests that spatial memory is impaired because of those mobility-related cognitive demands, rather than because of the limited visual information itself (the same participant wore the vision-restricting goggles throughout the experiment and completed half of the paths with the guide and half of the paths walking on his or her own). Experiment 3 of the current studies also supports the cognitive load hypothesis. Results from the within-subjects difference in Reaction Time measure suggest that navigating with restricted FOV may impair spatial learning because of the increased attentional demands necessary for safe navigation (mobility monitoring). This result will be further tested for FOV in the future using the guidance paradigm as in Rand, Creem-Regehr, and Thompson (2015). We will test the same participant's performance under restricted FOV on the spatial memory task in a guided condition (holding onto the experimenter's arm) and an unguided condition (walking on his or her own).

8.1. Cognitive Tradeoff

Results from Experiments 1-3 suggest that navigating and learning a new environment with 4° of the FOV seems to increase the cognitive load experienced by the navigator. Similar to Rand, Creem-Regehr, and Thompson's (2015) findings, the current study suggests that cognitive load increases as mobility monitoring demands increase. Increased need for mobility monitoring (and subsequent cognitive load) could occur in a variety of navigation situations. For example, older adults with motor decline may need to be more attentive to mobility monitoring to avoid potential obstacles and maintain stability that is threatened by normal age-related decline. This increased need for mobility monitoring is further exacerbated by visual impairment that also often occurs with old age. Young adults also experience the negative effects of greater cognitive load brought on by limited visual information. Rand et al. (2015) found that the greater cognitive load instigated by limiting the available visual information had negative effects on spatial memory. Indeed, even in a study of individuals with normal vision, results show that the ability to form allocentric mental maps of spatial locations is negatively affected by the addition of a concurrent task (Lindberg & Garling, 1982). Similarly, in their study of navigation aids, Klatzky et al. (2006) found that certain navigation aids actually impaired performance on a subsequent cognitive task (*N*-back) during virtual navigation, rather than helping as originally intended. Those aids that required more cognitive processing (i.e., directional language) worsened performance on the *N*-back task as compared to aids that functioned more at the perceptual level (sounds). Klatzky et al. (2006) argue that the language aids are detrimental compared to the sound aids because they increase cognitive load, which has negative effects on task performance. Taken together, these results and others show that greater cognitive load negatively affects performance on concurrent cognitive tasks.

Our current studies suggest that the demands of mobility monitoring increase as visual field restriction increases. While there was no effect of vision condition (15˚ vs. 60˚) on the secondary auditory reaction time task in Experiment 1, we did observe an effect on the secondary task in Experiment 2, when comparing 10˚ to 60˚. This difference between Experiments 1 and 2 suggests that 10˚ FOV may demand greater mobility monitoring than 15˚ FOV, which in turn affects cognitive load (but does not impair spatial memory yet). In Experiment 3, both reaction time and spatial memory were affected by vision condition (4˚ vs. 60˚). This suggests that the demands of safe mobility monitoring are greatly increased in the 4˚ vision condition and that this negatively affects spatial memory. Looking across the three studies, we see that as visual information becomes more and more limited, mobility-monitoring demands increase in a way that first affects cognitive load alone before affecting cognitive load in a way that impairs spatial memory.

8.2. Walking Speed

Results from Experiment 4 suggest that walking at a slower pace may offload the demands of mobility monitoring during navigation with severe visual impairment. This finding is consistent with prior research that shows that both younger and older people adopt a slower walking speed when completing a concurrent cognitive task (Alexander, Ashton-Miller, & Giordani, 2005; Kelly, Schrager, & Price, 2008). The current findings on walking speed add two components to the ongoing literature. First, our findings may help to explain *why* people adopt that slower walking speed—namely, to potentially address the greater demands of mobility monitoring. Second, our findings help to give some indication to the effectiveness of adopting a slower walking speed on concurrent cognitive task performance. Experiment 4 shows that walking slower may decrease cognitive load. Walking speed does not seem to affect spatial memory performance at 10° FOV, but it does have an effect on cognitive load.

For younger adults, walking is typically automatic and may be less affected by ongoing tasks compared to the walking patterns of older adults in the same situation (see the Dual-Process Model; as in Lovden, Schaefer, Pohlmeyer, & Lindenberger, 2008). As individuals get older, the cognitive control of walking becomes more demanding and cognitive control efficiency in general decreases. As such, the younger adults in our studies may have been less affected by the benefits of slower walking compared to the typical low vision population. However, as discussed in Rand, Creem-Regehr, and

Thompson (2015), there are many situations when mobility monitoring demands may increase, including visual impairment, pregnancy, injury, etc. Our findings support the idea that decreasing mobility monitoring demands by walking slower helps to reduce cognitive load. Future work will further test these ideas with older adults in similar real-world paradigms where we will test the more salient effect of actual age-related cognitive decline and potential visual impairment on walking speed, cognitive control, and spatial learning.

8.3. Limitations

Our ability to extend these findings to models of clinical low vision navigation is limited because of the uses of simulated field loss. Field loss is challenging to simulate in an ecologically valid manner, as it restricts the natural eye movements in a way that would not be experienced even by an individual with some type of peripheral field loss-related low vision. However, prior research suggests similar findings between simulated and actual peripheral field loss (see Fortenbaugh, 2008; Fortenbaugh, Hicks, Hao, & Turano, 2007). We are currently conducting similar studies with individuals with clinical low vision and plan to apply our findings from simulated vision loss to clinical settings. An additional limitation is that the effect of spatial memory was not observed until 4˚, when the goggles actually changed in structure more so than when moving from 15˚ to 10˚. The added cone to the simulation goggles may have been a novelty that affected performance in a way separate from the impact of the field restriction itself. However, in Mason's unpublished Honors thesis (Mason et al., 2014), the structure of the goggles involved a cone at all levels of field restriction and they still observed a strong drop-off in performance at 4˚. Therefore, it does not seem likely that the different goggle structure itself related to the spatial memory impairment. Additionally, results from these studies may apply uniquely to healthy younger adults, rather than generalizing to older adults who are more likely to suffer from an extreme visual impairment. Finally, the finding that restricted peripheral field at 10˚ affects reaction time but not spatial memory may be a reflection of the sensitivity of the task.

Our finding that walking slower may be more helpful for reducing cognitive load compared to walking faster may be an outcome of the manipulation of walking speed. In Experiment 4, all participants completed the first 2 of the 4 paths with no instruction about walking speed. Instead, we allowed them to adopt whatever walking speed felt natural and comfortable without bringing awareness to the pace. Only in the second 2 paths did we provide instruction and training about walking speed. Perhaps the difference in reaction time that we observed (slower reaction time in the faster walking condition) is less of an outcome of the strategic use of slower walking speed and more of an outcome of the added cognitive challenge of walking at a specified faster pace. We consciously chose the current design so as to test the effectiveness of naturally adopting a slower walking speed during a challenging task. However, future studies will counterbalance faster and slower walking speeds so that we can measure the effect of walking speed itself, rather than the potential confound of added awareness in the second 2 paths of the current experiment. Counterbalancing the order of walking speed will also allow us to account for potential practice/fatigue effects.

8.4. Implications and Future Directions

Findings from Experiments 1-3 suggest that a wide peripheral field is not necessary to effectively remember spatial locations learned through active navigation in novel spaces, for normally sighted younger adults in this paradigm. Findings from Experiment 4 suggest that adopting a slower walking speed may be an effective strategy for offloading the attentional costs of navigating and remembering spatial locations (i.e., decreasing the need for mobility monitoring), but does not account for the equivalent spatial memory found with severe (10°) and less severe (60°) restriction.

In future work, we may conduct a follow up study in which we will counterbalance the order of walking speed, such that half of participants will complete the first 2 paths at their chosen, presumably slower speed, and half of participants will complete the first 2 paths at the manipulated faster speed. We did not do this in Experiment 4, as we were wary of the possibility of bringing too much attention to the speed of walking. We wanted to test the effectiveness of the natural adoption of a slower walking speed without awareness, but it is possible that any effects of walking slower in the first 2 paths compared to faster in the second 2 paths may be confounded with experience/practice effects in the paradigm or, conversely, fatigue. Secondly, we are currently testing the walking speed hypothesis with a different type of extreme visual deficit—severely reduced acuity and contrast (as in Rand, Creem-Regehr, & Thompson, 2015). Finally, we are conducting an ongoing study with individuals with clinical low vision to measure the phenomenon in a more realistic, applicable, and ecologically valid way. However, there are also limitations with clinical studies, as there is much greater variability in age, visual deficit, and experience with navigating with vision loss.

CHAPTER 9

CONCLUSION

In a series of three studies, we examined how simulated severe peripheral field restriction (15˚, 10˚, and 4˚) affects spatial memory and cognitive load during a real-world navigation and spatial learning task. Results suggest a cognitive resource tradeoff as visual restriction moves from 15˚ (no effect on pointing error or cognitive load) to 10˚ (no effect on pointing error, significant effect of FOV restriction on cognitive load) to 4˚ (significant effect of FOV restriction on both pointing error and cognitive load). Results from Experiment 4 suggest that slower walking speed works as an effective strategy to offload the cognitive costs of navigating with FOV restriction (by reducing cognitive load), but does not improve pointing accuracy. These results have implications for clinical low-vision settings and for developing useful assistive devices for navigation with visual impairment.

APPENDIX A

VISION TEST RESULTS FOR ALL PARTICIPANTS

Experiment 1.

Participant	Eye Height	LogMar Acuity	Snellen Acuity	Dominant Eye	15˚ Aperture Test (average of 2)	60˚ Aperture Test (average of 2)
1	69.5	0.08	20/24.0453	Left	17.6407591	60.35203163
2	62	0.04	20/21.9296	Left	18.18055384	61.75362616
3	58	0.04	20/21.9296	Left	31.41727566	82.61722803
4	68	0	20/20	Left	18.75412139	66.77702715
5	68	0.02	20/20.9426	Right	17.16724296	66.33092838
6	63	0.08	20/24.0453	Right	17.13186155	59.61157127
7	64	0.14	20/27.6077	Left	19.364702	67.9929183
8	60.75	0	20/20	Right	16.07142142	63.21500449
9	58.25	0.04	20/21.9296	Left	31.41727566	66.03645197
10	60.5	0.04	20/21.9296	Right	21.90812529	76.36590104
11	63	0.02	20/20.9426	Right	17.49232453	61.75362616
12	64.5	0.06	20/22.9631	Left	22.93007415	69.24831016
13	62	0.04	20/21.9296	Left	21.23931055	67.83880462
14	62.5	0.08	20/240453	Left	22.68124232	73.62141562
15	61.75	0	20/20	Right	18.79646599	67.38013505
16	60	0.08	20/24.0453	Left	17.27426283	63.76189518
17	67.25	0	20/20	Right	16.35625796	63.21500449
18	61	0.04	20/21.9296	Right	18.62821458	66.33092838
19	60.25	0.02	20/20.9426	Left	22.49808863	70.87560292
20	60.5	0.06	20/22.963	Left	16.07142142	78.6889767

Experiment 1. Continued

Participant	Eye Height	LogMar Acuity	Snellen Acuity	Dominant Eye	15˚ Aperture Test (average of 2)	60˚ Aperture Test (average of 2)
21	66	0	20/20	Left	12.45165813	59.48976259
22	64.5	0.12	20/26.3651	Left	14.10461202	73.26822775
23	65.5	0	20/20	Right	11.84608172	62.14611554
24	62.5	0	20/20	Right	14.80975611	78.6889767
25	65.5	0	20/20	Right	12.56498418	65.89008173
26	58.25	0.3	20/39.9052	Right	16.00945771	66.47904045
27	61.75	0.18	20/30.2712	Right	11.54865181	55.38878319
28	59.75	0.06	20/22.9631	Right	12.83757346	63.76189518
29	60	0.06	20/22.9631	Left	14.17695136	64.038526
30	59.75	0	20/20	Right	15.67696849	70.8092354
31	66.75	0.12	20/26.3651	Right	17.79171394	77.70674868
32	64.5	0.06	20/22.9631	Right	12.26723971	73.62141562

Experiment 2.

Participant	Eye Height	LogMar Acuity	Snellen Acuity	Dominant Eye	10˚ Aperture Test (average of 2)	60˚ Aperture Test (average of 2)
1	61	0.04	20/21.9296	Right	12.01801191	56.920352
2	66	0.04	20/21.9296	Right	11.5357778	63.89994289
3	63.5	0.08	20/24.0453	Right	10.24984669	67.5324161

Experiment 2. Continued

Participant	Eye Height	LogMar Acuity	Snellen Acuity	Dominant Eye	10˚ Aperture Test (average of 2)	60˚ Aperture Test (average of 2)
4	63	0	20/20	Right	9.729028876	57.2632308
5	62.5	0.2	20/31.6979	Right	9.566961898	60.85499142
6	59.75	0.02	20/20.9426	Right	10.67847361	61.23721082
7	71.5	0.08	20/24.0453	Right	10.02622751	63.21500449
8	66	0.08	20/24.0453	Right	10.43603425	57.48630874
9	66.25	0	20/20	Right	10.24984669	64.31730925
10	58.75	0	20/20	Right	14.61151907	84.59209667
11	61.75	0.08	20/24.0453	Right	11.95554718	74.15670661
12	60.5	0.1	20/25.1785	Right	12.5421549	69.4080925
13	56.5	0.04	20/21.9296	Left	10.77862352	70.38046871
14	60.25	0.02	20/20.9426	Right	11.25349143	70.87560292
15	58.5	0.1	20/25.1785	Left	10.88066406	63.07959356
16	60.5	0.18	20/30.2712	Right	12.01801191	81.76362059
17	66.5	0	20/20	Right	9.333716743	62.14611554

Experiment 2. Continued

Participant	Eye Height	LogMar Acuity	Snellen Acuity	Dominant Eye	10˚ Aperture Test (average of 2)	60˚ Aperture Test (average of 2)
18	66	0	20/20	Left	10.34210484	60.728542
19	68	0.02	20/20.9426	Right	9.812133971	54.5472402
20	60.5	0	20/20	Left	10.38885782	61.75362616
21	70	0.16	20/28.9088	Right	9.371799679	58.06264519
22	62.5	0.22	20/33.1917	Right	12.2745119	66.47904045
23	61.5	0	20/20	Left	11.96	67.99
24	62	0.14	20/27.6077	Right	12.82	65.02
25	64.5	0.04	20/21.9296	Left	11.04	73.27
26	62.75	0.02	20/20.9426	Left	13.99	96.79
27	62.5	0.02	20/20.9426	Right	10.63	0
28	68.75	0	20/20	Right	11.42	70.88

Experiment 3.

Participant	Eye Height	LogMar Acuity	Snellen Acuity	Dominant Eye	4˚ Aperture Test (average of 2)	60˚ Aperture Test (average of 2)

Experiment 3. Continued

Participant	Eye Height	LogMar Acuity	Snellen Acuity	Dominant Eye	4˚ Aperture Test (average of 2)	60˚ Aperture Test (average of 2)
1	60	0.06	20/22.9631	Left	5.158295001	64.73956787
2	60.5	0.02	20/20.9426	Right	5.375937931	63.89994289
3	58	0.06	20/22.9631	Right	4.211028378	61.88395869
4	60	0.08	20/24.0453	Left	4.150052723	59.7338337
5	65.75	0.3	20/39.9052	Right	5.000821129	64.73956787
6	63	0.02	20/20.9426	Left	3.524782047	72.05474677
7	63.5	0.2	20/31.6979	Left	4.234358544	65.74428622
8	61.25	0	20/20	Right	3.977275713	57.25869469
9	68.25	0	20/20	Right	4.142554649	54.65113991
10	63	0.12	20/26.3651	Left	4.655630178	63.07959356
11	70	0	20/20	Right	4.509149932	60.47706447
12	67	0.16	20/28.9088	Left	4.811941033	70.5448429
13	66	0.12	20/26.3651	Right	4.862962223	67.38013505
14	62.5	0	20/20	Right	4.636802082	64.17764721

Experiment 3. Continued

Participant	Eye Height	LogMar Acuity	Snellen Acuity	Dominant Eye	4˚ Aperture Test (average of 2)	60˚ Aperture Test (average of 2)
15	63	0.06	20/20.9631	Left	4.135083609	61.49444045
16	66.5	0.04	20/21.9296	Right	4.273821708	96.24426092
17	66	0.04	20/21.9296	Left	4.322158976	66.18339988
18	67	0.22	20/33.1917	Left	4.562987538	68.30300014
19	65.5	0.02	20/20.9426	Right	6.057397157	73.97753677
20	69.5	0.02	20/20.9426	Right	3.856844627	64.17764721
21	62.5	0	20/20	Left	4.305925578	65.89008173
22	64.5	0.02	20/20.9426	Right	4.811941033	74.33662093
23	62	0	20/20	Right	4.273821708	71.88422374
24	62	0.04	20/21.9296	Left	3.977275713	73.97753677
25	61.5	0.14	20/27.6077	Right	6.204853364	86.64472107
26	62	0.04	20/21.9296	Right	4.599598844	73.62141562
27	68.5	0.04	20/21.9296	Right	5.350853312	80.51020159
28	56.25	0.02	20/20.9426	Right	4.925633352	81.1329076

Experiment 4.

Participant	Eye Height	Logmar Acuity	Snellen Acuity	Dominant Eye	10˚ Aperture Test (average of 2)
1	62.5	0.04	20/21.9296	Right	11.42118627
2	68	0	20/20	Right	9.770405136
3	66.5	0.06	20/22.9631	Right	12.89351076
4	66	0.04	20/21.9296	Left	11.42118627
5	61.75	0.02	20/20.9426	Right	12.68038349
6	60.75	0.02	20/20.9426	Right	12.08113037
7	57	0	20/20	Left	9.448903394
8	63	0	20/20	Left	11.77197567
9	63	0.02	20/20.9426	Right	11.65268406
10	58.5	0	20/20	Left	14.07588153
11	58.75	0.04	20/21.9296	Right	9.939481456
12	62.5	0	20/20	Left	9.004378984
13	60	0	20/20	Right	13.41967362
14	60	0.06	20/22.9631	Right	12.96614739
15	57.5	0.02	20/20.9426	Right	12.2745119
16	61	0.06	20/22.9631	Right	12.34035019
17	62	0	20/20	Right	12.2745119
18	63.5	0	20/20	Left	9.939481456
19	64	0.08	20/24.0453	Right	12.5421549
20	61.5	0.08	20/24.0453	Right	12.2745119
21	62.5	0.04	20/21.9296	Left	10.77862352

Experiment 4. Continued

Participant	Eye Height	Logmar Acuity	Snellen Acuity	Dominant Eye	10˚ Aperture Test (average of 2)
22	63	0	20/20	Left	9.770405136
23	60	0	20/20	Right	15.29002654
24	62.5	0.04	20/21.9296	Left	13.90591494
25		0.12	20/26.3651	Right	17.23129637
26	61	0.1	20/25.1785	Right	10.48363989
27	65	0.16	20/28.9088	Right	13.41967362
28	60.5	0.06	20/22.9631	Right	11.42118627

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